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⑤④ Process for preparing xanthomonas heteropolysaccharide, heteropolysaccharide as prepared by the latter process and its use.

⑤⑦ Process for preparing Xanthomonas heteropolysaccharide from *Xanthomonas campestris* NCIB 11854 and use of the latter e.g. as viscosity modifier in an aqueous solution, and in a drilling fluid and use in connection with well-treatments, and enhanced oil recovery.

EP 0 130 647 A2

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PROCESS FOR PREPARING XANTHOMONAS
HETEROPOLYSACCHARIDE, HETEROPOLYSACCHARIDE
AS PREPARED BY THE LATTER PROCESS AND ITS USE

The present invention relates to a process for preparing Xanthomonas heteropolysaccharide by fermenting a certain Xanthomonas species.

5 From US 3,485,719 it is known that heteropolysaccharides can be prepared by subjecting a carbohydrate source to fermentation by the organism Xanthomonas campestris NRRL B-1459. In this patent specification it is stated that the heteropolysaccharide produced from Xanthomonas campestris NRRL B-1459 has shown to be an exceptionally effective agent when
10 used in secondary oil recovery operations as well as exhibiting utility as a thickening agent for foodstuffs, cosmetics etc., and also as an edible film-forming agent, and as an emulsifying agent for example in printing ink and as thickening agent in textile print pastes.

15 Applicants have now isolated a novel substrain of Xanthomonas campestris species which has been deposited at the National Collection of Industrial Bacteria, Torry Research Station, Aberdeen, under accession number 11854. Compared with the microorganism Xanthomonas campestris NRRL B-1459 the
20 present microorganism NCIB 11854 appears to exhibit a much higher specific growth rate in a defined medium, a remarkably higher specific rate of polymer production and can be maintained in continuous culture or repeated fill-and-draw

culture for considerably longer periods without deterioration in polymer producing capability.

Furthermore for enhanced oil recovery operations the potential injectivity of the heteropolysaccharide produced by the NCIB 11854 microorganism, as determined by a filtration test, is as good as or is even better than that of the heteropolysaccharide produced by the Xanthomonas campestris NRRL B-1459 especially when dissolved in high salinity brines. The present invention provides a process for preparing Xanthomonas heteropolysaccharide which comprises growing the organism Xanthomonas campestris NCIB 11854 in an aqueous nutrient medium by aerobic fermentation of an assimilable carbohydrate and nitrogen source and recovering the heteropolysaccharide. The process may suitably be carried out as a batch-process or a fed-batch process with or without fill and draw or as a continuous process.

From productivity considerations a continuous process or a fill and draw process is preferred. Unlike many commonly available Xanthomonas strains, the Xanthomonas campestris NCIB 11854 organism appears not to require complex growth factors or vitamins in order to achieve satisfactory growth rates and polymer production rates in liquid culture. Very good results can be achieved if the organisms is grown in a simple chemically defined medium containing a simple nitrogen source such as sodium glutamate, or an ammonium or nitrate salt. Therefore such a growth medium is preferably used. Sodium glutamate is the preferred nitrogen source.

Furthermore the use of a chemically defined growth medium allows better control of the microbial growth conditions, resulting in a controlled polymer synthesis and a reproducible production process yielding a product of consistent quality. This type of control over heteropolysaccharide production and quality is not generally possible using, for instance, Xanthomonas campestris NRRL B-1459 when grown in growth media containing the more variable and complex nitrogen sources such

as yeast extract or distillers dried solubles. The present invention further relates to the heteropolysaccharide as prepared by the process as hereinbefore described and to the use of the heteropolysaccharide as viscosity modifier in an aqueous solution.

A drilling fluid comprising water and 0.06-1.5% by weight of the above heteropolysaccharide is a further aspect of the present invention. The present invention also encompasses a method of treating a well comprising the introduction into the well of an aqueous medium comprising water and 0.05-1.5% by weight of the above heteropolysaccharide as well as a method for displacing a fluid through a well and/or a permeable subsurface formation communicating with the well by injecting into the well an aqueous solution comprising the above heteropolysaccharide. The present invention further relates to a biologically pure culture of Xanthomonas campestris NCIB 11854.

The present invention will now be further illustrated by the following Example.

Example

Preparation of heteropolysaccharide by cultivation of Xanthomonas campestris Sp. NCIB 11854 and a comparison of its performance with that of Xanthomonas campestris NRRL B-1459

Xanthomonas campestris NCIB 11854 was grown on three different chemically defined salts media (as shown in Table 1) in a Chemap GF 7 litre fermentation vessel under batch conditions as summarised in Table 2.

In the first experiment the sole source of nitrogen for microbial growth was ammonium ion (24 mM), allowing exponential growth of cells to a maximum concentration of 3 gl^{-1} . In the second and third experiments the ammonium was substituted with nitrate (24 mM) and glutamate (24 mM) respectively. The results are shown in Figures 1-3.

As is clear from a comparison of these figures glutamate as a nitrogen source is preferred since it gives a μ_{max} i.e.

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- 4 -

maximum cell growth rate, of 0.12 h^{-1} , a q_p value, i.e.
 specific rate of polymer production, of $0.36 \text{ g. (g}^{-1}\text{)h}^{-1}$ and a
 final polymer yield Y_p of 0.59 g.g^{-1} . This combination of high
 μ_{max} and high q_p resulted in a final polymer productivity of
 5 $0.49 \text{ g. (l}^{-1}\text{)h}^{-1}$, which is more than double the normal
 productivity of a heteropolysaccharide fermentation using
Xanthomonas campestris NRRL B - 1459

Table 3 indicates under A the values of μ_{max} , q_p , q_g , i.e.
 specific glucose utilisation rate, Y_p , i.e. yield of polymer on
 10 glucose and p , i.e. polymer product, for Xanthomonas campestris
NCIB 11854 on the above defined salts growth medium and under B
 the respective values for Xanthomonas campestris NRRL B-1459

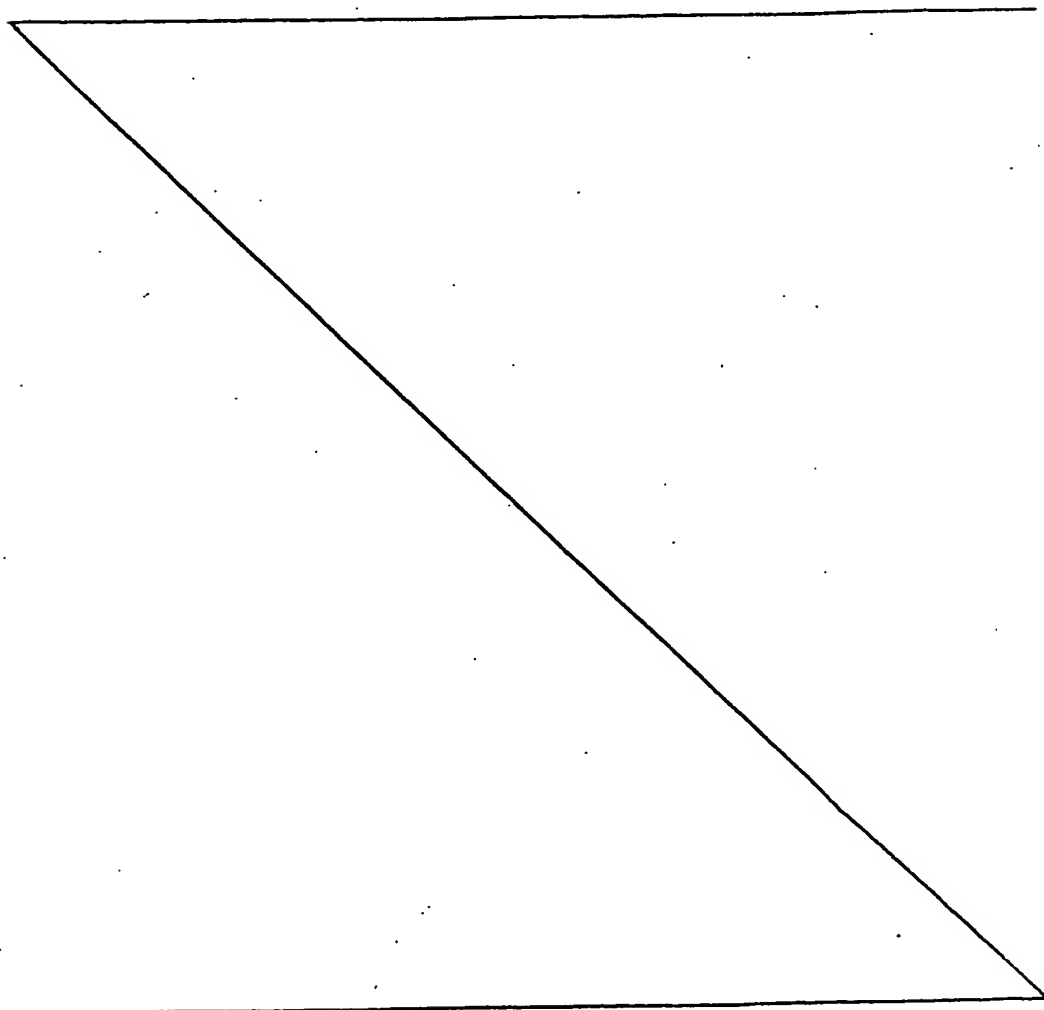


TABLE 1
CHEMICALLY DEFINED SALTS MEDIUM FOR THE CULTURE OF XANTHOMONAS
CAMPESTRIS NCIB 11854

Component	Concentration (mM)		
	Medium 1	Medium 2	Medium 3
Glucose	24.5 (gl ⁻¹)	24.3 (gl ⁻¹)	23.4 (gl ⁻¹)
(NH ₄) ₂ SO ₄	12 (24 mM N)	-	-
NaNO ₃	-	24	-
Na Glutamate	-	-	24
KH ₂ PO ₄	25	25	25
Na ₂ HPO ₄	25	25	25
MgSO ₄ ·7H ₂ O	2	2	2
CaCl ₂ ·2H ₂ O	1	1	1
FeSO ₄ ·7H ₂ O	0.2	0.2	0.2
MnSO ₄ ·7H ₂ O	20 x 10 ⁻³	20 x 10 ⁻³	20 x 10 ⁻³
ZnSO ₄ ·7H ₂ O	20 x 10 ⁻³	20 x 10 ⁻³	20 x 10 ⁻³
CuSO ₄ ·5H ₂ O	20 x 10 ⁻³	20 x 10 ⁻³	20 x 10 ⁻³
CoCl ₂ ·6H ₂ O	10 x 10 ⁻³	10 x 10 ⁻³	10 x 10 ⁻³
H ₃ BO ₃	10 x 10 ⁻³	10 x 10 ⁻³	10 x 10 ⁻³
Na ₂ MoO ₄ ·2H ₂ O	10 x 10 ⁻³	10 x 10 ⁻³	10 x 10 ⁻³
KI	10 x 10 ⁻³	10 x 10 ⁻³	10 x 10 ⁻³

mM = millimolar

gl⁻¹ = grams/liter

mM N = millimolar nitrogen

TABLE 2
GROWTH CONDITIONS FOR THE CULTURE
OF XANTHOMONAS CAMPESTRIS NCIB 11854

Temperature	28°C
pH	6.8
Impeller	3 x 4 Bladed Rushton turbine
Impeller speed	1000 rpm
Culture volume	4.5 - 5.0 litres
pH control	1N NaOH + 1N KOH
Dissolved O ₂ tension	>80 mm Hg
Air flow rate	1.0 litres/minute

TABLE 3
KINETIC DATA FROM THE CULTURE OF XANTHOMONAS CAMPESTRIS NCIB 11854 (A)
AND XANTHOMONAS CAMPESTRIS NRRL B - 1459 (B) ON DEFINED SALTS GROWTH MEDIUM

Run	Nitrogen Source	μ_{\max} (h ⁻¹)	qp [g(g ⁻¹)h ⁻¹]	qq [g(g ⁻¹)h ⁻¹]	Yp [g(g ⁻¹)]	P [g(l ⁻¹)h ⁻¹]
A	1 Ammonia	0.09	0.275	0.60	0.53	0.39
	2 Nitrate	0.084	0.35	0.60	0.52	0.38
	3 Glutamate	0.12	0.36	0.68	0.59	0.49
B	1 Ammonia	0.03	0.08	ND	0.51	0.13
	2 Glutamate	0.07	0.11	ND	0.41	0.21

ND = not determined

This table clearly shows the better performance of Xanthomonas campestris NCIB 11854 compared with Xanthomonas campestris NRRL B-1459.

- 5 In Table 4 the filterability of Xanthomonas campestris NCIB 11854 broth is compared with that of Xanthomonas campestris NRRL B - 1459 broth when diluted to constant viscosity in solutions of different salinities".

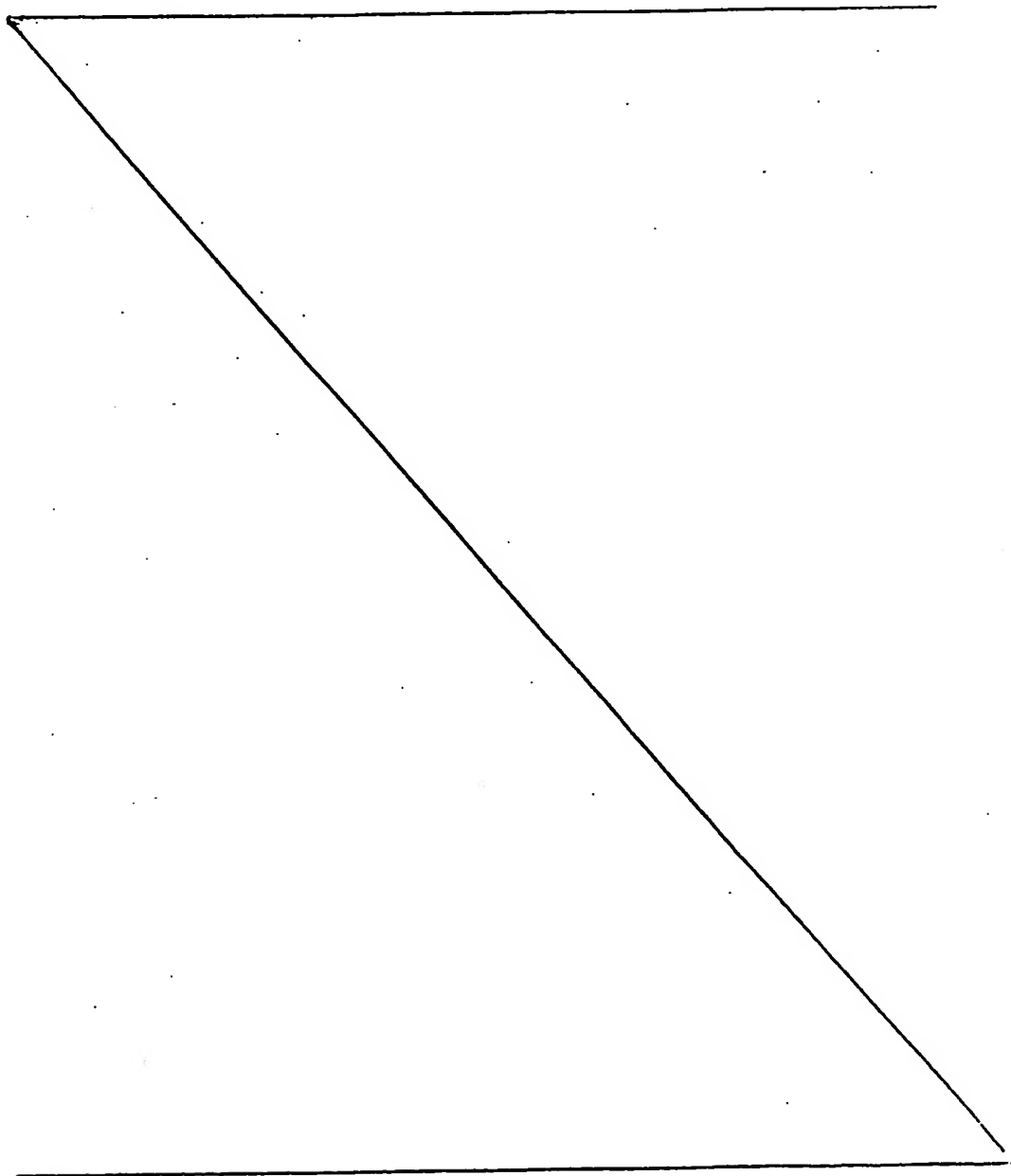


TABLE 4

FILTERABILITY OF 20cP SOLUTIONS (viscosity measured at shear rate of 7.5 sec⁻¹)

A IN 1% NaCl + 0.1% CaCl₂ AT 30°C, 1 atm over pressure

STRAIN	SAMPLE	FILTRATION TIME (SECS) FOR 200mls	
		5μ+P/F*	1.2μ**
NCIB 11854	Broth	11.0	63.0
	Enzyme Treat.	9.5	29.3
NRRL B-1459	Broth	17.5	59.6
	Enzyme Treat.	19.0	188.0

B IN 1% NaCl + 0.1% CaCl₂ AT 70°C, 1 atm overpressure

NCIB 11854	Broth	7.5	37.3
	Enzyme Treat	5.5	17.0
NRRL B-1459	Broth	35.8	50.7
	Enzyme Treat	8.5	40.9

C IN 15% NaCl + 1.5% CaCl₂ AT 30°C, 1 atm overpressure

NCIB 11854	Broth	14.5	330
	Enzyme Treat	22.1	101
NRRL B-1459	Broth	30.8	81.7
	Enzyme Treat	>1000	>1000

D IN 15% NaCl + 1.5% CaCl₂ AT 70°C, 1 atm overpressure

NCIB 11854	Broth	17.0	299
	Enzyme Treat	>1000	>1000
NRRL B-1459	Broth	>1000	>1000
	Enzyme Treat	>1000	>1000

* P/F = Prefilter for separation of coarse material.

** without Prefilter, but solution previously passed through 5μ

+ P/F.

For the actual filtration Millipore (trade mark) filters having a diameter of 47mm have been used. 5μ and 1.2μ are sizes of the pores of these filters.

As is clear from the above table the filterability of Xanthomonas campestris NCIB 11854 broth before and after enzyme treatment is remarkably better than that of Xanthomonas campestris NRRL B-1459.

- 5 Characterisation by the National Collection of Industrial Bacteria of Xanthomonas campestris NCIB 11854 and Xanthomonas campestris NCIB 11803 = NRRL B -1459, hereafter referred to as NCIB 11854 and NCIB 11803 respectively.

The results were similar for NCIB 11803 and NCIB 11854 except where stated

10 Cell Morphology

- A. Oxoid CMI Nutrient Broth + 0.75% Difco Agar plates were inoculated with 'young' growth and incubated for 7½ hours at 25°C. Cells from the margins of c. 0.2 mm patches of growth were examined and photographed in situ under coverslips by phase-contrast. Mobility and the other features were determined in pools surrounding 0.1 mm glass beads scattered on other patches. Cells at the margins of growth occurred singly and in pairs, with cell dimensions of 0.4-0.5 µm width x 1.2-2.5µm length for NCIB 11803 and 0.5-0.6µm x 1.2-2.5µm for NCIB 11854. In from the growth margin in pools, aggregates (sympasmata? See Graham & Hodgkiss, 1967) of a hundred to several thousand cells were commonly seen with NCIB 11803 but much less frequently with NCIB 11854. Mobility was positive.
- 25 B. Using conditions as in A above but with 0.5% glucose added to the medium and 7 hours incubation result were similar except that cells were 0.1 µm wider and aggregates were not seen with NCIB 11854.

30 Colony Morphology

- A. After 48 hours growth at 30°C on Oxoid CM3 Nutrient Agar plates growth was good, and isolated colonies were yellow in colour, circular, entire, mucoid, smooth, string and convex. Colony diameter was 1-1.5 mm for 11803 and 1.5mm for NCIB 11854.
- 35

- B. After 72 hours growth at 30°C on medium as in A above but with 1% glucose growth was good and isolated colonies were pale cream in colour, circular, entire, very mucoid, smooth and convex, while confluent growth was pale cream-yellow. Colony diameter was 2mm for NCIB 11803 and 2-2.5 mm for 11854.

Selected Morphology

Mineral Base Palleroni 6 Doudoroff 1972 Modified (PD) (A. Rev.

Phytophethol. 10, 73)

10	Na ₂ HPO ₄ · 12H ₂ O	6.0 g
	KH ₂ PO ₄	2.4 g
	NH ₄ Cl	1.0 g
	MgSO ₄ · 7H ₂ O	0.5 g
	FeCl ₃ · 6H ₂ O	0.01 g
15	CaCl ₂ · 6H ₂ O	0.01 g
	Deionized water	1 litre

The ptt will be 6.8

PD Mineral Base + 0.1% Filter-Sterilized Glucose (PDG)

Gelatin Stabs

20	Nutrient Broth No. 2 (Oxoid)	2.5%
	Gelatin (Difco)	12.0%

Gelatin Plates

	Nutrient Agar Oxoid CM3	2.8%
	Gelatin	1.0%

Milk Plates

25	Skim Milk (Difco) Separately sterilised	3%
	Peptone (Difco)	0.1%
	Beef Extract Lab-Lemco	0.1%
	NaCl	0.5%
30	Agar	1.5%

pH 7.4 before autoclaving

Biochemical Characteristics: at 30°C except as stated

Growth at °C on CM3 Plates

	Temperature	5°	30°	37°
35	Growth (non-quantitative)	+	+	-

pH Growth Range on CMI broth (adjusted pH)

pH	3	5	7.2	8	9	10
Growth	-	3+	3+	3+	3+	3+

Growth in Presence of Salt

- 5 Basal media containing NaCl at concentrations of 2,3,4 and 5% were prepared according to the method of Hayward & Hodgkiss (1961). Cultures were incubated for 3 days.

NCIB 11854 was less salt tolerant than NCIB 11803 as follows

	NaCl %	2	3	4	5
10	NCIB 11803 growth	3+	3+	3+	-
	NCIB 11854 growth	3+	3+	+	-

Hydrolysis of Gelatin and Casein

- 15 Cultures were incubated for 7 days. Gelatin stabs were at 20°C. NCIB 11854 showed a lesser degree of proteolytic activity than NCIB 11803 as follows

	Gelatin Stab	Gelatin Plate	Milk Plate
NCIB 11803	+	+	+
NCIB 11854	-	+	weak +

Growth Factor Requirement Tests

- 20 Subcultures were made by straight wire three times in PDG medium made with glass distilled water. Satisfactory growth was obtained in about 4 days indicating there was no absolute requirement for growth factors.

Methionine Stimulation Test

- 25 One drop each of a faintly turbid young growing culture in PDG medium made with glass distilled water was inoculated into PDG with and without 10 µg/ml L-methionine in 1 ml amounts in 16mm tubes. There was no stimulation of the growth rate by L-methionine.

Carbon Source Utilization

- 30 PD medium with 0.1% filter-sterilized sole carbon sources shown in Table 1 were inoculated and incubated for 14 days. Three apparently minor differences in growth between the strains were found.

Acid Production from Carbohydrates

The oxidation-fermentation medium of Hayward and Hodgkiss (1961) was supplemented with 1% filter-sterilized carbon sources shown in Table 1. The tubes were inoculated and incubated for 14 days. Acid was produced from galactose and melibiose by NCIB 11854 but not by NCIB 11803. The significance of this is doubtful particularly because both compounds were utilized as sole carbon sources by both NCIB 11854 and NCIB 11803.

TABLE 1

Carbon Source Utilization - Compounds listed in the tables for Pseudomonas in Bergey's Manual of Determinative Bacteriology 1974 and in the order for Pseudomonas in R.Y. Stanier et al. (1966) J. gen. Microbiol. 43, 159.

	Acid production from O-F medium		Growth from sole carbon source	
	NCIB 11803	NCIB 11854	NCIB 11803	NCIB 11854
<u>Carbohydrates and sugar derivatives</u>				
D-Ribose			-	-
D-Xylose	trace	-	weak	weak
L-Arabinose	weak	weak	-	-
L-Rhamnose			-	-
D-Glucose	+	+	+	+
D-Fructose	+	+	+	+
Sucrose	+	+	+	+
Trehalose	+	+	+	+
Cellobiose	weak	+	+	+
2-Ketogluconate			-	-
Saccharate				
<u>Fatty acids</u>				
Acetate			weak	weak
Propionate			-	-
Butyrate			-	-
<u>Dicarboxylic acids</u>				
Malonate			weak	<+

Table 1 (continued)

	Acid production from O-F medium		Growth from sole carbon source	
	NCIB 11803	NCIB 11854	NCIB 11803	NCIB 11854
<u>Hydroxy acids</u>				
D (-)-Tartrate			-	-
meso-Tartrate			-	-
DL-3-Hydroxybutyrate			-	-
DL-Lactate			-	-
Glycollate			-	-
<u>Miscellaneous organic acids</u>				
Levulinate			-	-
Citraconate			-	-
Mesaconate			-	-
<u>Sugar Polyalcohols and glycols</u>				
Erythritol			-	-
Sorbitol	-	-	-	-
meso-Inositol	-	-	-	-
Adonitol			-	-
Propylene glycol			-	-
2,3-Butylene glycol			-	-
D-Mannitol*	weak	+	-	<weak
Glycerol*	+	+	-	<weak
<u>Alcohols</u>				
Methanol*			-	-
Ethanol			-	-
Geraniol				
<u>Non-nitrogenous aromatic and other cyclic compounds</u>				
meta-Hydroxybenzoate			-	-
para-Hydroxybenzoate				
Testosterone				
<u>Aliphatic amino acids</u>				
L-Valine			-	-
L-Arginine +			-	-
<u>Amino acids containing a ring structure</u>				
Histidine			-	-
L-Tryptophan*			-	-
Anthranilate*			-	-

Table 1 (continued)

	Acid production from O-F medium		Growth from sole carbon source	
	NCIB 11803	NCIB 11854	NCIB 11803	NCIB 11854
<u>Amines</u>				
Benzylamine*			-	-
Tryptamine				
-Amylamine				
<u>Miscellaneous nitrogenous compounds</u>				
Betaine				
Pantothenate				
<u>Carbohydrates and sugar derivatives continued</u>				
Galactose*	-	+	+	+
Mannose*	+	+	+	+
Lactose*	-	-	-	-
Maltose*	+	+	+	+
Melibiose*	-	+	+	+

* Additional compound

+ In place of DL-

Table 2
Gram-negative non-fermentatives

Isolate NCIB	11803	11854	11803	11854	11803	11854
°C incubation	30	30	30	30	30	30
Pyocyanin Fluorescence L-Arg CSU Betaine CSU	brown diffusible pigment in the culture broth		Gas glucose ONPG Arg Møller Lys Møller	- - -	5° 30° 37°	+ + -
Glucose CSU			Orn Møller	-	Growth at pH	-
Lactate CSU			NO ₃ ⁻ to NO ₂ ⁻	-	3 5 7.2	3+ 3+ 3+
Acetate CSU			NO ₃ ⁻ to N ₂	-	8	3+
Sensitivity			Residual NO ₃ ⁻	+	9	3+
			DNA ase		10	3+
Penicillin G	-	-	Gel stab 20°	+7	Growth in NaCl	3+
Streptomycin	+++	+++	Gel plate	+	2% 3% 4% 5%	3+ 3+ 3+ -
Chloramphen. Tetracycline	+++ +++	+++ +++	Casein Starch	+ +		
Novobiocin Polymyxin B O/129 Levan	+ +	+ ++	Lecith egg Lipase egg NH ₃ Indole	- - + -	brown diffusible pigment in the tryptone water culture	

Table 2 (continued)
Gram-negative non-fermentatives

Isolate NCIB	11803	11854	11803	11854	11803	11854
°C incubation	30	30	30	30	30	30
Growth factor requirement	- (glucose CSU)	- (glucose CSU)	H ₂ S (TSI) +lead acetate paper Tween 80	- weak+	- weak+	
Urease Christenson	-	-	MR	-	-	
Litmus milk	peptonised reduced	peptonised reduced	VP	-	-	
			Arg Thornley	-	-	

These tests indicate limited differences so the main differences are that T.1188 exhibits better kinetics of polymer production in a defined medium, better growth with inorganic nitrogen, especially NH_4^+ and stability in continuous culture in a defined medium.

References

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CLAIMS

1. A process for preparing Xanthomonas heteropolysaccharide which comprises growing the organism Xanthomonas campestris NCIB 11854 in an aqueous nutrient medium by aerobic fermentation of an assimilable carbohydrate and nitrogen source and recovering the heteropolysaccharide.
2. A process as claimed in claim 1 which is carried out as a continuous process or as a fill and draw process.
3. A process as claimed in claim 1 or 2 in which the organism is grown in the absence of yeast extract in a chemically defined medium as hereinbefore defined.
4. A process as claimed in any one of the claims 1-3 in which glutamate is used as nitrogen source.
5. Heteropolysaccharide as prepared by a process as claimed in any one of the claims 1-4.
6. The use of a heteropolysaccharide as claimed in claim 5 as a viscosity modifier in an aqueous solution.
7. A drilling fluid comprising water and 0.06 - 1.5% by weight of a heteropolysaccharide as claimed in claim 5.
8. A method of treating a well comprising the introduction into the well of an aqueous medium comprising water and 0.05 - 1.5% by weight of a heteropolysaccharide as claimed in claim 5.
9. A method for displacing a fluid through a well and/or a permeable subsurface formation communicating with the well

by injecting into the well an aqueous solution comprising a heteropolysaccharide as claimed in claim 5.

10. A biologically pure culture of the Xanthomonas campestris NCIB 11854.

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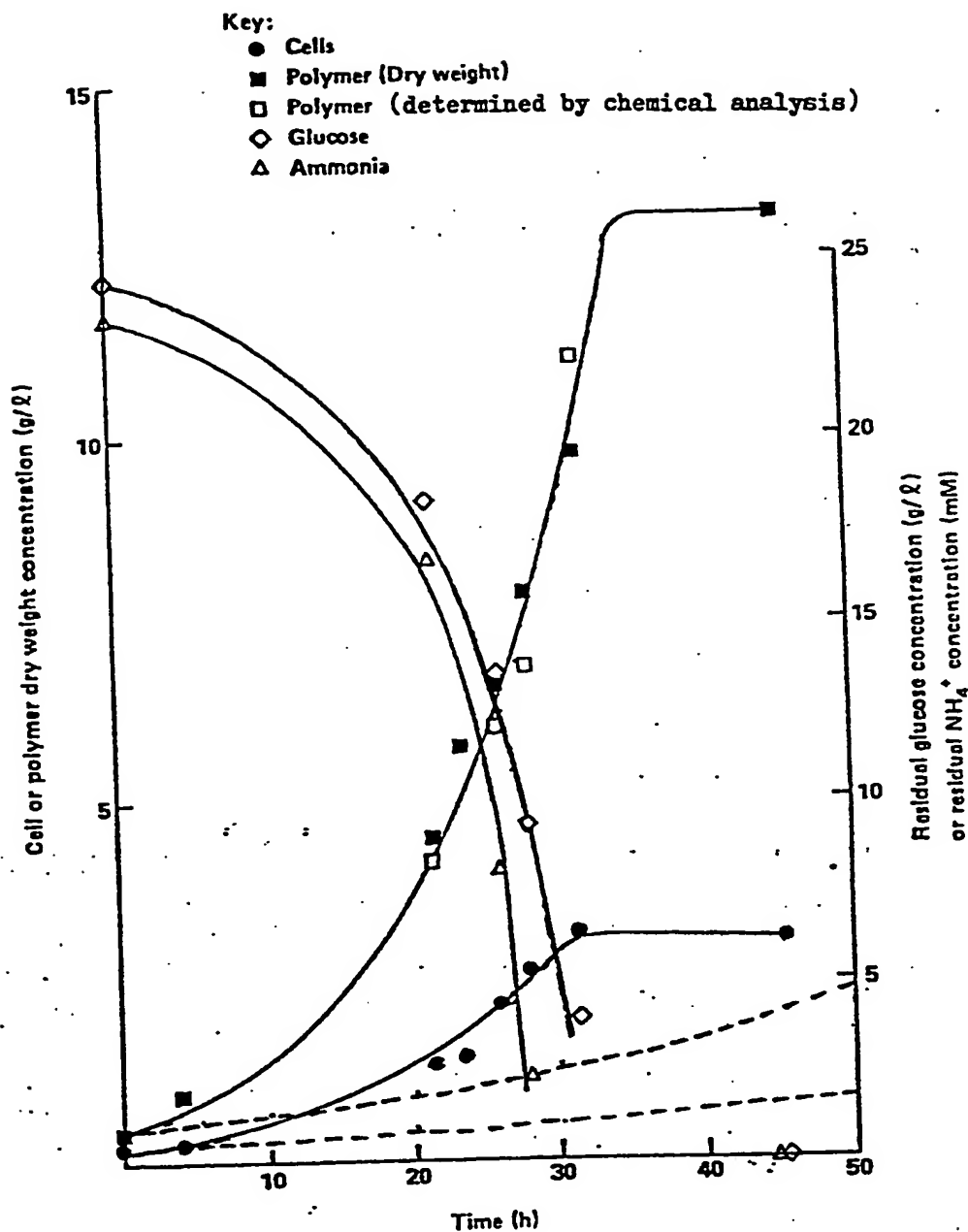


Fig 1. Growth and Polymer Production by *X.campestris* NCIB 11854 (solid Lines) and *X.campestris* NRRL B-1459 (dashed Lines: top, polymer; bottom, cells) in defined salts medium (1) Ammonia as nitrogen source.

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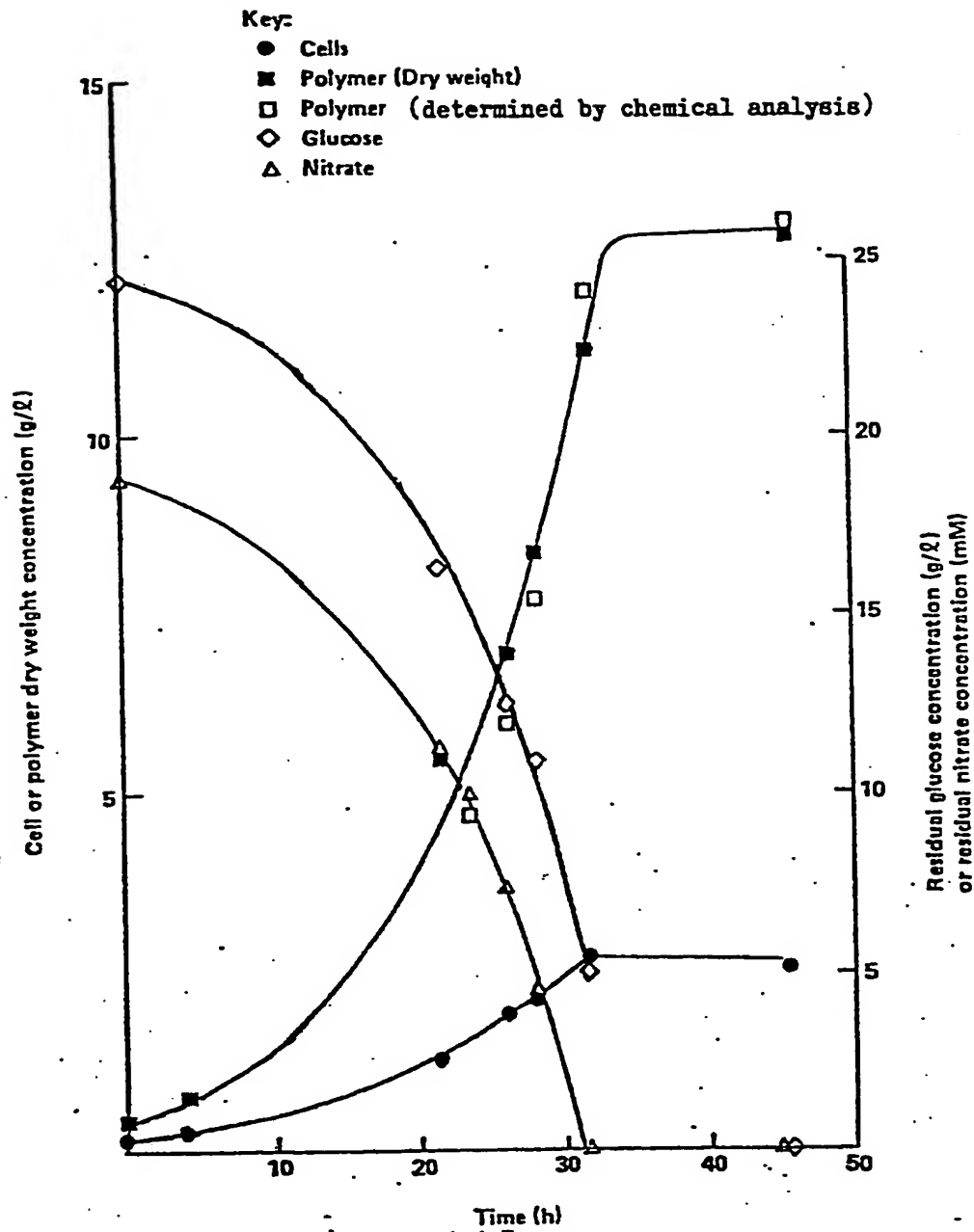


Fig 2. Growth and Polymer Production by *X.campestris* NCIB 11854 in defined salts medium (2) Nitrate as nitrogen source.

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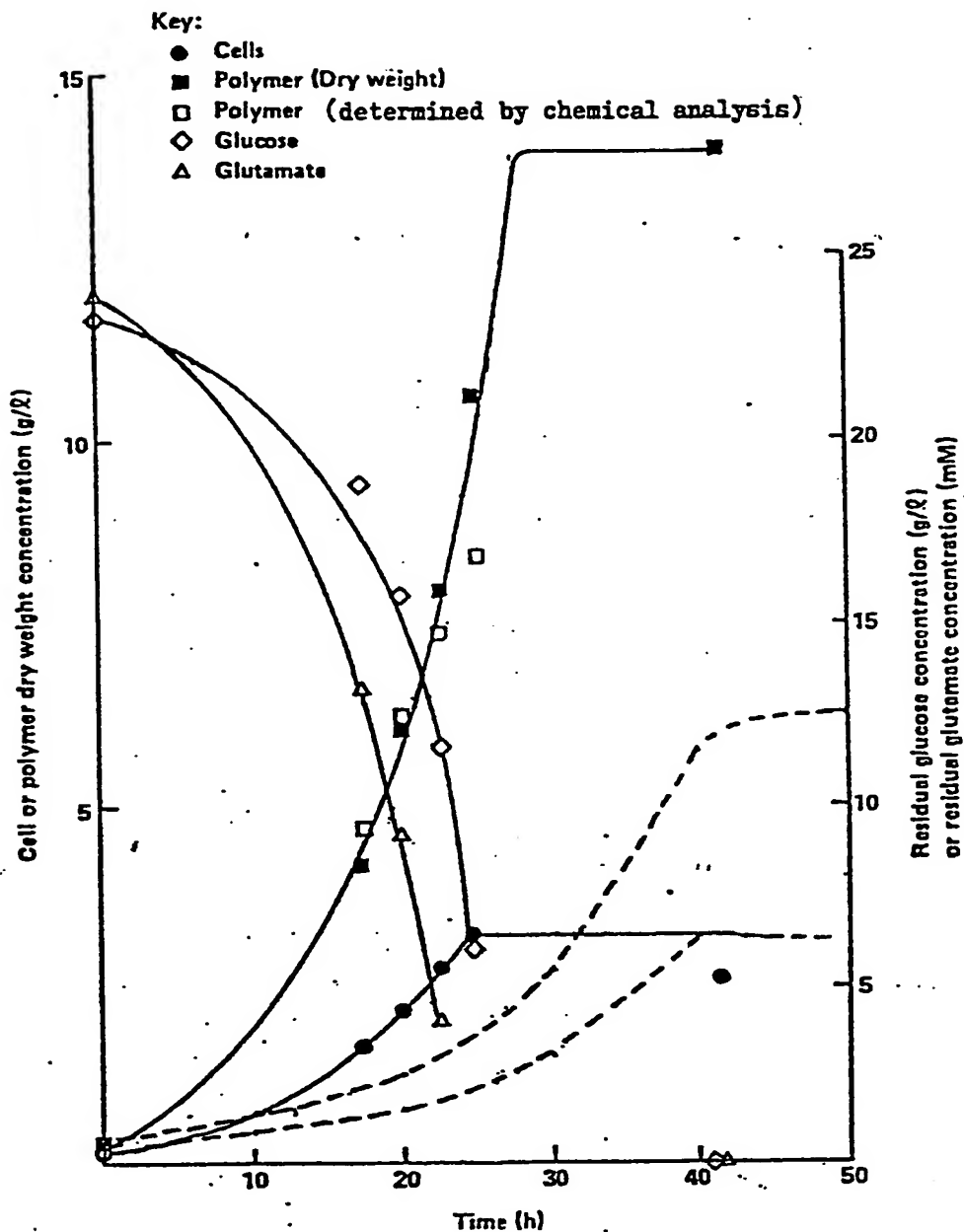


Fig-3. Growth and Polymer Production by *X.campestris* NCIB 11854 (solid Lines) and *X.campestris* NRRL B-1459 (dashed Lines: top, polymer; bottom, cells) in defined salts medium (3) Glutamate as nitrogen source.

(19)



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(54) **Process for preparing xanthomonas heteropolysaccharide, heteropolysaccharide as prepared by the latter process and its use.**

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(50) References cited:
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FR-A-2 328 770
FR-A-2 408 653
US-A-4 301 247
US-A-4 328 308

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Courier Press, Leamington Spa, England.

Description

The present invention relates to a process for preparing *Xanthomonas* heteropolysaccharide by fermenting a certain *Xanthomonas* species.

From US 3,485,719 it is known that heteropolysaccharides can be prepared by subjecting a carbohydrate source to fermentation by the organism *Xanthomonas campestris* NRRL B-1459. In this patent specification it is stated that the heteropolysaccharide produced from *Xanthomonas campestris* NRRL B-1459 has shown to be an exceptionally effective agent when used in secondary oil recovery operations as well as exhibiting utility as a thickening agent for foodstuffs, cosmetics, etc., and also as an edible film-forming agent, and as an emulsifying agent for example in printing ink and as thickening agent in textile print pastes.

Applicants have now isolated a novel substrain of *Xanthomonas campestris* species which has been deposited at the National Collection of Industrial Bacteria, Torry Research Station, Aberdeen, under accession number 11854. Compared with the microorganism *Xanthomonas campestris* NRRL B-1459 the present microorganism NCIB 11854 appears to exhibit a much higher specific growth rate in a defined medium, a remarkably higher specific rate of polymer production and can be maintained in continuous culture or repeated fill-and-draw culture for considerably longer periods without deterioration in polymer producing capability.

Furthermore for enhanced oil recovery operations the potential injectivity of the heteropolysaccharide produced by the NCIB 11854 microorganism, as determined by a filtration test, is as good as or is even better than that of the heteropolysaccharide produced by the *Xanthomonas campestris* NRRL B-1459 especially when dissolved in high salinity brines. The present invention provides a process for preparing *Xanthomonas* heteropolysaccharide which comprises growing the organism *Xanthomonas campestris* NCIB 11854 in an aqueous nutrient medium by aerobic fermentation of an assimilable carbohydrate and nitrogen source and recovering the heteropolysaccharide. The process may suitably be carried out as a batch-process or a fed-batch process with or without fill and draw or as a continuous process.

From productivity considerations a continuous process or a fill and draw process is preferred. Unlike many commonly available *Xanthomonas* strains, the *Xanthomonas campestris* NCIB 11854 organism appears not to require complex growth factors or vitamins in order to achieve satisfactory growth rates and polymer production rates in liquid culture. Very good results can be achieved if the organisms is grown in a simple chemically defined medium containing a simple nitrogen source such as sodium glutamate, or an ammonium or nitrate salt. Therefore such a growth medium is preferably used. Sodium glutamate is the preferred nitrogen source.

Furthermore, the use of a chemically defined growth medium allows better control of the microbial growth conditions, resulting in a controlled polymer synthesis and a reproducible production process yielding a product of consistent quality. This type of control over heteropolysaccharide production and quality is not generally possible using, for instance, *Xanthomonas campestris* NRRL B-1459 when growth in growth media containing the more variable and complex nitrogen sources such as yeast extract or distillers dried solubles. The present invention further relates to the heteropolysaccharide as prepared by the process as hereinbefore described and to the use of the heteropolysaccharide as viscosity modifier in an aqueous solution.

A drilling fluid comprising water and 0.06—1.5% by weight of the above heteropolysaccharide is a further aspect of the present invention. The present invention also encompasses a method of treating a well comprising the introduction into the well of an aqueous medium comprising water and 0.05—1.5% by weight of the above heteropolysaccharide as well as a method for displacing a fluid through a well and/or a permeable subsurface formation communicating with the well by injecting into the well an aqueous solution comprising the above heteropolysaccharide. The present invention further relates to a biologically pure culture of *Xanthomonas campestris* NCIB 11854.

The present invention will now be further illustrated by the following Example.

Example

Preparation of heteropolysaccharide by cultivation of *Xanthomonas campestris* Sp. NCIB 11854 and a comparison of its performance with that of *Xanthomonas campestris* NRRL B-1459.

Xanthomonas campestris NCIB 11854 was grown on three different chemically defined salts media (as shown in Table 1) in a Chemap GF 7 litre fermentation vessel under batch conditions as summarised in Table 2.

In the first experiment the sole source of nitrogen for microbial growth was ammonium ion (24 mM), allowing exponential growth of cells to a maximum concentration of 3 g l⁻¹. In the second and third experiments the ammonium was substituted with nitrate (24 mM) and glutamate (24 mM) respectively. The results are shown in Figures 1—3.

As is clear from a comparison of these figures glutamate as a nitrogen source is preferred since it gives a μ_{max} , i.e. maximum cell growth rate, of 0.12 h⁻¹, a gp value, i.e. specific rate of polymer production, of 0.36 g. (g⁻¹)h⁻¹ and a final polymer yield Yp of 0.59 g.g⁻¹. This combination of high μ_{max} and high gp resulted in a final polymer productivity of 0.49g.(l⁻¹)h⁻¹, which is more than double the normal productivity of a heteropolysaccharide fermentation using *Xanthomonas campestris* NRRL B-1459. Table 3

EP 0 130 647 B1

indicates under A the value of μ_{\max} gp.gg, i.e. specific glucose utilisation rate Yp, i.e. yield of polymer on glucose and p, i.e. polymer product, for *Xanthomonas campestris* NCIB 11854 on the above defined salts growth medium and under B the respective values for *Xanthomonas campestris* NRRL B-1459.

TABLE 1

CHEMICALLY DEFINED SALTS MEDIUM FOR THE CULTURE OF XANTHOMONAS
CAMPESTRIS NCIB 11854

Component	Concentration (mM)		
	Medium 1	Medium 2	Medium 3
Glucose	24.5 (gl ⁻¹)	24.3 (gl ⁻¹)	23.4 (gl ⁻¹)
(NH ₄) ₂ SO ₄	12 (24 mM N)	-	-
NaNO ₃	-	24	-
Na Glutamate	-	-	24
KH ₂ PO ₄	25	25	25
Na ₂ HPO ₄	25	25	25
MgSO ₄ ·7H ₂ O	2	2	2
CaCl ₂ ·2H ₂ O	1	1	1
FeSO ₄ ·7H ₂ O	0.2	0.2	0.2
MnSO ₄ ·7H ₂ O	20 x 10 ⁻³	20 x 10 ⁻³	20 x 10 ⁻³
ZnSO ₄ ·7H ₂ O	20 x 10 ⁻³	20 x 10 ⁻³	20 x 10 ⁻³
CuSO ₄ ·5H ₂ O	20 x 10 ⁻³	20 x 10 ⁻³	20 x 10 ⁻³
CoCl ₂ ·6H ₂ O	10 x 10 ⁻³	10 x 10 ⁻³	10 x 10 ⁻³
H ₃ BO ₃	10 x 10 ⁻³	10 x 10 ⁻³	10 x 10 ⁻³
Na ₂ MoO ₄ ·2H ₂ O	10 x 10 ⁻³	10 x 10 ⁻³	10 x 10 ⁻³
KI	10 x 10 ⁻³	10 x 10 ⁻³	10 x 10 ⁻³

mM = millimolar

gl⁻¹ = grams/liter

mM N = millimolar nitrogen

EP 0 130 647 B1

TABLE 2
GROWTH CONDITIONS FOR THE CULTURE
OF XANTHOMONAS CAMPESTRIS NCIB 11854

Temperature	28°C
pH	6.8
Impeller	3 x 4 Bladed Rushton turbine
Impeller speed	1000 rpm
Culture volume	4.5 - 5.0 litres
pH control	1N NaOH + 1N KOH
Dissolved O ₂ tension	>80 mm Hg
Air flow rate	1.0 litres/minute

TABLE 3
KINETIC DATA FROM THE CULTURE OF *XANTHOMONAS CAMPESTRIS* NCIB 11854 (A)
AND *XANTHOMONAS CAMPESTRIS* NRRL B - 1459 (B) ON DEFINED SALTS GROWTH MEDIUM

Run	Nitrogen Source	μ_{\max} (h ⁻¹)	q_p (g(g ⁻¹)h ⁻¹)	q_g (g(g ⁻¹)h ⁻¹)	Y_p (g(g ⁻¹))	P (g(l ⁻¹)h ⁻¹)
A	1 Ammonia	0.09	0.275	0.60	0.53	0.39
	2 Nitrate	0.084	0.35	0.60	0.52	0.38
	3 Glutamate	0.12	0.36	0.68	0.59	0.49
B	1 Ammonia	0.03	0.08	ND	0.51	0.13
	2 Glutamate	0.07	0.11	ND	0.41	0.21

ND = not determined

EP 0 130 647 B1

This table clearly shows the better performance of *Xanthomonas campestris* NCIB 11854 compared with *Xanthomonas campestris* NRRL B-1459.

In Table 4 the filterability of *Xanthomonas campestris* NCIB 11854 broth is compared with that of *Xanthomonas campestris* NRRL B-1459 broth when diluted to constant viscosity in solutions of different salinities*.

TABLE 4

FILTERABILITY OF 20cP SOLUTIONS (viscosity measured at shear rate of 7.5 sec⁻¹)

A IN 1% NaCl + 0.1% CaCl₂ AT 30°C, 1 atm over pressure

STRAIN	SAMPLE	FILTRATION TIME (SECS) FOR 200mls	
		5μ+P/F*	1.2μ**
NCIB 11854	Broth	11.0	63.0
	Enzyme Treat.	9.5	29.3
NRRL B-1459	Broth	17.5	59.6
	Enzyme Treat.	19.0	188.0

B IN 1% NaCl + 0.1% CaCl₂ AT 70°C, 1 atm overpressure

NCIB 11854	Broth	7.5	37.3
	Enzyme Treat	5.5	17.0
NRRL B-1459	Broth	35.8	50.7
	Enzyme Treat	8.5	40.9

C IN 15% NaCl + 1.5% CaCl₂ AT 30°C, 1 atm overpressure

NCIB 11854	Broth	14.5	330
	Enzyme Treat	22.1	101
NRRL B-1459	Broth	30.8	81.7
	Enzyme Treat	>1000	>1000

D IN 15% NaCl + 1.5% CaCl₂ AT 70°C, 1 atm overpressure

NCIB 11854	Broth	17.0	299
	Enzyme Treat	>1000	>1000
NRRL B-1459	Broth	>1000	>1000
	Enzyme Treat	>1000	>1000

* P/F = Prefilter for separation of coarse material.

** without Prefilter, but solution previously passed through 5μ

+ P/F.

For the actual filtration Millipore (trade mark) filters having a diameter of 47mm have been used. 5μ and 1.2μ are sizes of the pores of these filters.

As is clear from the above table the filterability of *Xanthomonas campestris* NCIB 11854 broth before and after enzyme treatment is remarkably better than that of *Xanthomonas campestris* NRRL B-1459.

Characterisation by the National Collection of Industrial Bacteria of *Xanthomonas campestris* NCIB 11854 and *Xanthomonas campestris* NCIB 118903 = NRRL B-1459, hereafter referred to as NCIB 11854 and NCIB 11803 respectively.

The results were similar for NCIB 11803 and NCIB 11854 except where stated.

EP 0 130 647 B1

Cell Morphology:

- A. Oxoid CMI Nutrient Broth + 0.75% Difco Agar plates were inoculated with 'young' growth and incubated for 7½ hours at 25°C. Cells from the margins of c. 0.2 mm patches of growth were examined and photographed in situ under coverslips by phase-contrast. Mobility and the other features were determined in pools surrounding 0.1 mm glass beads scattered on other patches. Cells at the margins of growth occurred singly and in pairs, with cell dimensions of 0.4—0.5 µm width x 1.2—2.5 µm length for NCIB 11803 and 0.5—0.6 µm x 1.2—2.5 µm for NCIB 11854. In from the growth margin in pools, aggregates (sympasmata? See Graham & Hodgkiss, 1967) of a hundred to several thousand cells were commonly seen with NCIB 11803 but much less frequent with NCIB 11854. Mobility was positive.
- B. Using conditions as in A above but with 0.5% glucose added to the medium and 7 hours incubation results were similar except that cells were 0.1 µm wider and aggregates were not seen with NCIB 11854.

Colony Morphology

- A. After 48 hours growth at 30°C on Oxoid CM3 Nutrient Agar plates growth was good, and isolated colonies were yellow in colour, circular, entire, mucoid, smooth, string and convex. Colony diameter was 1—1.5 mm for 11803 and 1.5 mm for NCIB 11854.
- B. After 72 hours growth at 30°C on medium as in A above but with 1% glucose growth was good and isolated colonies were pale cream in colour, circular, entire, very mucoid, smooth and convex, while confluent growth was pale cream-yellow. Colony diameter was 2 mm for NCIB 11803 and 2—2.5 mm for 11854.

Selected Morphology

Mineral Base Palleroni 6 Doudoroff 1972 Modified (PD). (A. Rev. Phytophethol. 10, 73)

	Na ₂ HPO ₄ 12H ₂ O	6.0 g
25	KH ₂ PO ₄	2.4 g
	NH ₄ Cl	1.0 g
	MgSO ₄ ·7H ₂ O	0.5 g
	FeCl ₃ ·6H ₂ O	0.01 g
	CaCl ₂ ·6H ₂ O	0.01 g
30	Deionized Water	1 Litre
	The ppt will be 6.8	
	PD Mineral Base + 0.1% Filter-Sterilised Glucose (PDG)	
	Gelatin Stabs	
	Nutrient Broth No. 2 (Oxoid)	2.5%
35	Gelatin (Difco)	12.0%
	Gelatin Plates	
	Nutrient Agar Oxoid CM3	2.8%
	Gelatin	1.0%
	Milk Plates	
40	Skim Milk (Difco) Separately sterilised	3%
	Peptone (Difco)	0.1%
	Beef Extract Lab-Lemco	0.1%
	NaCl	0.5%
	Agar	1.5%
45	pH 7.4 before autoclaving	

Biochemical Characteristics: at 30°C except as stated
Growth at °C on CM3 Plates

	Temperature	5°	30°	37°			
	Growth (non quantitative)	+	+	—			
50	pH Growth Range on CMI broth (adjusted pH)						
	pH	3	5	7.2	8	9	10
	Growth	—	3+	3+	3+	3+	3+

Growth in Presence of Salt

- Basal media containing NaCl at concentrations of 2,3,4 and 5% were prepared according to the method of Hayward & Hodgkiss (1961). Cultures were incubated for 3 days.
- NCIB 11854 was less salt tolerant than NCIB 11803 as follows:

	NaCl %	2	3	4	5
60	NCIB 11038 growth	3+	3+	3+	—
	NCIB 11854 growth	3+	3+	+	—

Hydrolysis of Gelatin and Casein

Cultures were incubated for 7 days. Gelatin stabs were at 20°C. NCIB 11854 showed a lesser degree of proteolytic activity than NCIB 11803 as follows:

EP 0 130 647 B1

	Gelatin Stab	Gelatin Plate	Milk Plate
NCIB 11803	+	+	+
NCIB 11854	-	+	weak +

Growth Factor Requirement Tests

Subcultures were made by straight wire three times in PDG medium made with glass distilled water. Satisfactory growth was obtained in about 4 days indicating there was no absolute requirement for growth factors.

Methionine Stimulation Test

One drop each of a faintly turbid young growing culture in PDG medium made with glass distilled water was inoculated into PDG with and without 10 µg/ml L-methionine in 1 ml amounts in 16mm tubes. There was no stimulation of the growth rate by L-methionine.

Carbon Source Utilization

PB medium with 0.1% filter-sterilized sole carbon sources shown in Table 1 were inoculated and incubated for 14 days. Three apparently minor differences in growth between the strains were found.

Acid Production from Carbohydrates

The oxidation-fermentation medium of Hayward & Hodgkiss (1961) was supplemented with 1% filter-sterilized carbon sources shown in Table 5. The tubes were inoculated and incubated for 14 days. Acid was produced from galactose and melibiose by NCIB 11854 but not by NCIB 11803. The significance of this is doubtful particularly because both compounds were utilized as sole carbon sources by both NCIB 11854 and NCIB 11803.

TABLE 5

Carbon Source Utilization - Compounds listed in the tables for *Pseudomonas* in Bergey's Manual of Determinative Bacteriology 1974 and in the order for *Pseudomonas* in R.Y. Stanier et al. (1966) J. gen. Microbiol. 43, 159.

	Acid production from O-F medium		Growth from sole carbon source	
	NCIB 11803	NCIB 11854	NCIB 11803	NCIB 11854
<u>Carbohydrates and sugar derivatives</u>				
D-Ribose			-	-
D-Xylose	trace	-	weak	weak
L-Arabinose	weak	weak	-	-
L-Rhamnose			-	-
D-Glucose	+	+	+	+
D-Fructose	+	+	+	+
Sucrose	+	+	+	+
Trehalose	+	+	+	+
Cellobiose	weak	+	+	+
2-Ketogluconate				
Saccharate			-	-
<u>Fatty acids</u>				
Acetate			weak	weak
Propionate			-	-
Butyrate			-	-
<u>Dicarboxylic acids</u>				
Malonate			weak	<+

Table 5 (continued)

	Acid production from O-F medium		Growth from sole carbon source	
	NCIB 11803	NCIB 11854	NCIB 11803	NCIB 11854
<u>Hydroxy acids</u>				
D (-)-Tartrate			-	-
meso-Tartrate			-	-
DL-3-Hydroxybutyrate			-	-
DL-Lactate			-	-
Glycollate			-	-
<u>Miscellaneous organic acids</u>				
Levullinate			-	-
Citraconate			-	-
Mesaconate			-	-
<u>Sugar Polyalcohols and glycols</u>				
Erythritol			-	-
Sorbitol	-	-	-	-
meso-Inositol	-	-	-	-
Adonitol			-	-
Propylene glycol			-	-
2,3-Butylene glycol			-	-
D-Mannitol*	weak	+	-	<weak
Glycerol*	+	+	-	<weak
<u>Alcohols</u>				
Methanol*			-	-
Ethanol			-	-
Geraniol				
<u>Non-nitrogenous aromatic and other cyclic compounds</u>				
meta-Hydroxybenzoate			-	-
para-Hydroxybenzoate			-	-
Testosterone				
<u>Aliphatic amino acids</u>				
L-Valine			-	-
L-Arginine +			-	-
<u>Amino acids containing a ring structure</u>				
Histidine			-	-
L-Tryptophan*			-	-
Anthranilate*			-	-

EP 0 130 647 B1

Table .5 (continued)

	Acid production from O-F medium		Growth from sole carbon source	
	NCIB 11803	NCIB 11854	NCIB 11803	NCIB 11854
<u>Amines</u>				
Benzylamine*			-	-
Tryptamine				
-Amylamine				
<u>Miscellaneous nitrogenous compounds</u>				
Betaine				
Pantothenate				
<u>Carbohydrates and sugar derivatives continued</u>				
Galactose*	-	+	+	+
Mannose*	+	+	+	+
Lactose*	-	-	-	-
Maltose*	+	+	+	+
Melibiose*	-	+	+	+

* Additional compound

+ In place of DL-

Table 6
Gram-negative non-fermentatives

Isolate NCIB	11803	11854	11803	11854	11803	11854
°C incubation	30	30	30	30	30	30
Pyocyanin						
Fluorescence						
I-Arg CSU	brown diffusible pigment in the culture broth		Gas glucose			
Betaine CSU			ONPG			
			Arg Møller			
			Lys Møller			
Glucose CSU			Orn Møller			
Lactate CSU			NO ₃ ⁻ to NO ₂ ⁻			
Acetate CSU			NO ₃ ⁻ to N ₂			
Sensitivity			Residual NO ₃ ⁻			
			DNA ase			
Penicillin G	-	-	Cell stab 20°	+7	-7	
Streptomycin	+++	+++	Cell plate	+	+	
Chloramphen.	+++	+++	Casein	+	weak+	
Tetracycline	+++	+++	Starch	+	+	
Novobiocin	+	+	Lecith egg	-	-	
Polymyxin B	+	++	Lipase egg	-	-	
0/129			NH ₄	+	+	
Levan			Indole	-	-	
						brown diffusible pigment in the tryptone water culture

Table 6 (continued)
Gram-negative non-fermentatives

Isolate NCIB	11803	11854	11803	11854	11803	11854
°C incubation	30	30	30	30	30	30
Growth factor requirement	- (glucose CSU)	- (glucose CSU)	H ₂ S (TSI) +lead acetate paper Tween 80	- weak+	- weak+	- weak+
Urease Christenson	-	-	MR	-	-	-
Litmus milk	peptonised reduced	peptonised reduced	VP	-	-	-
			Arg Thornley	-	-	-

These tests indicate limited differences so the main differences are that T.1188 exhibits better kinetics of polymer production in a defined medium, better growth with inorganic nitrogen, especially NH_4^+ and stability in continuous culture in a defined medium.

References

1. Bergey's Manual of Determinative Bacteriology, 8th edn (1974).
(R.E. Buchanan & N.E. Gibbons, eds). Baltimore: Williams & Wilkins.
2. Cowan, S.T. & Steel, K.J. (1974). Manual for the Identification of Medical Bacteria.
Cambridge University Press.

Claims

1. A process for preparing *Xanthomonas heteropolysaccharide* which comprises growing the organism *Xanthomonas campestris* NCIB 11854 in an aqueous nutrient medium by aerobic fermentation of an assimilable carbohydrate and nitrogen source and recovering the heteropolysaccharide.
2. A process as claimed in claim 1 which is carried out as a continuous process or as a fill and draw process.
3. A process as claimed in claim 1 or 2 in which the organism is grown in the absence of yeast extract in a chemically defined medium as hereinbefore defined.
4. A process as claimed in any one of the claims 1—3 in which glutamate is used as nitrogen source.
5. Heteropolysaccharide as prepared by a process as claimed in any one of the claims 1—4.
6. The use of a heteropolysaccharide as claimed in claim 5 as a viscosity modifier in an aqueous solution.
7. A drilling fluid comprising water and 0.06—1.5% by weight of a heteropolysaccharide as claimed in claim 5.
8. A method of treating a well comprising the introduction into the well of an aqueous medium comprising water and 0.05—1.5% by weight of a heteropolysaccharide as claimed in claim 5.
9. A method for displacing a fluid through a well and/or a permeable subsurface formation communicating with the well by injecting into the well an aqueous solution comprising a heteropolysaccharide as claimed in claim 5.
10. A biologically pure culture of the *Xanthomonas campestris* NCIB 11854.

Patentansprüche

1. Verfahren zur Herstellung eines *Xanthomonas*-Heteropolysaccharids, welches ein Vermehren des Organismus *Xanthomonas campestris* NCIB 11854 in einem wäßrigen Nährmedium durch aerobe Fermentation einer assimilierbaren Kohlenhydrat- und Stickstoffquelle und ein Gewinnen des Heteropolysaccharids umfaßt.
2. Verfahren nach Anspruch 1, welches als ein kontinuierliches Verfahren oder als ein Füll- und -Abziehverfahren ausgeführt wird.
3. Verfahren nach Anspruch 1 oder 2, worin der Mikroorganismus in Abwesenheit von Hefeextrakt in einem chemisch definierten Medium gemäß vorstehender Definition vermehrt wird.
4. Verfahren nach einem der Ansprüche 1 bis 3, worin Glutamat als Stickstoffquelle verwendet wird.
5. Heteropolysaccharid, hergestellt nach einem Verfahren, wie in einem der Ansprüche 1 bis 4 beansprucht.
6. Verwendung eines Heteropolysaccharids, wie in Anspruch 5 beansprucht, als Viskositätsmodifizierungsmittel in einer wäßrigen Lösung.
7. Bohrflüssigkeit, umfassend Wasser und 0,06 bis 1,5 Gew.-% eines Heteropolysaccharids, wie in Anspruch 5 beansprucht.
8. Verfahren zur Behandlung einer Ölbohrung, umfassend das Einbringen eines wäßrigen, Wasser und 0,05 bis 1,5 Gew.-% eines Heteropolysaccharids, wie in Anspruch 5 beansprucht, aufweisenden Mediums in die Ölbohrung.
9. Verfahren zum Verdrängen eines Fluids durch eine Ölbohrung und/oder eine permeable unterirdische Formation, die mit der Ölbohrung in Verbindung steht, durch Injizieren einer wäßrigen, ein Heteropolysaccharid gemäß Anspruch 5 umfassenden Lösung in die Bohrung.
10. Biologisch reine Kultur von *Xanthomonas campestris* NCIB 11854.

Revendications

1. Procédé de préparation d'un hétéropolysaccharide de *Xanthomonas*, qui comprend la culture de l'organisme *Xanthomonas campestris* NCIB 11854, dans un milieu nutritif aqueux, par fermentation aérobie d'une source assimilable d'hydrate de carbone et d'azote, et la récupération de l'hétéropolysaccharide.
2. Procédé selon la revendication 1, qui est réalisé comme un procédé continu ou comme un procédé par remplissage et soutirage.
3. Procédé selon la revendication 1 ou 2, dans lequel l'organisme est cultivé en l'absence d'extrait de levure, dans un milieu défini chimiquement tel que défini ci-dessus.
4. Procédé selon l'une quelconque des revendications 1—3, dans lequel on utilise le glutamate comme source d'azote.
5. Hétéropolysaccharide préparé par un procédé selon l'une quelconque des revendications 1—4.
6. Utilisation d'un hétéropolysaccharide selon la revendication 5, comme agent modifiant la viscosité dans une solution aqueuse.
7. Fluide de forage comprenant de l'eau et 0,06—1,5% en poids d'un hétéropolysaccharide selon la revendication 5.

EP 0 130 647 B1

8. Procédé de traitement d'un puits, comprenant l'introduction, dans le puits, d'un milieu aqueux comprenant de l'eau et 0,05—1,5% en poids d'un hétéropolysaccharide selon la revendication 5.

9. Procédé pour déplacer un fluide à travers un puits et/ ou une formation souterraine perméable communiquant avec le puits, qui consiste à injecter dans le puits une solution aqueuse comprenant un hétéropolysaccharide selon la revendication 5.

10. Culture biologiquement pure de *Xanthomonas campestris* NCIB 11854.

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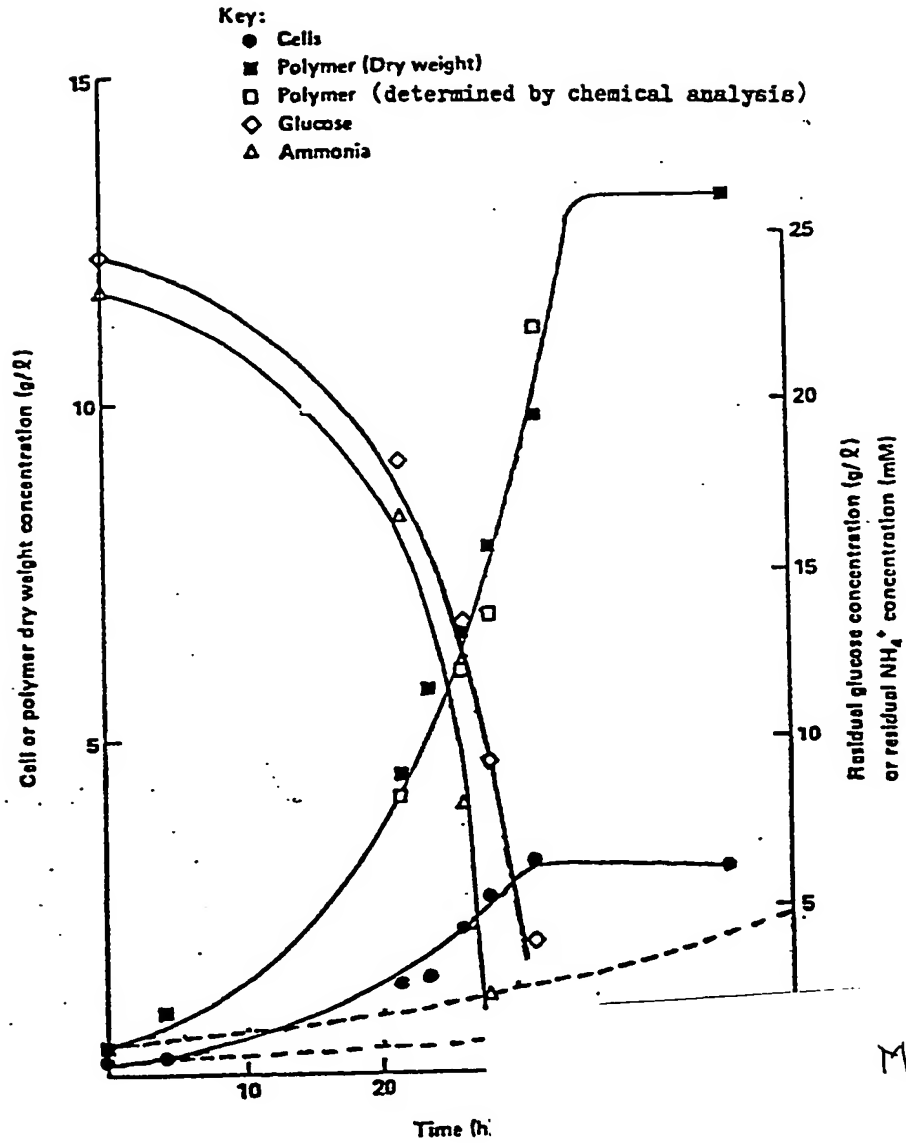


Fig 1. Growth and Polymer Production (solid lines) and *X.campestris* NRRL B-polymer; bottom, cells) in defined sal nitrogen source.

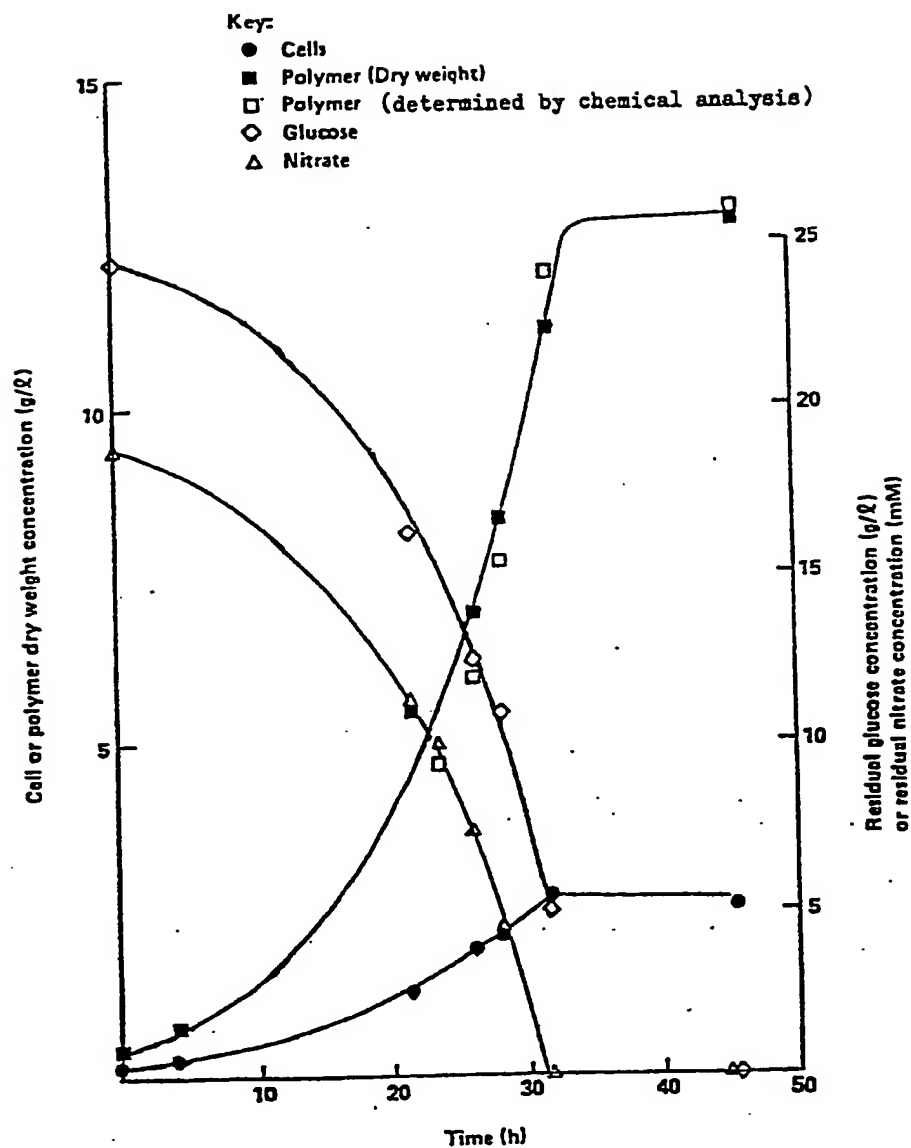


Fig 2. Growth and Polymer Production by *X.campestris* NCIB 11854 in defined salts medium (2) Nitrate as nitrogen source.

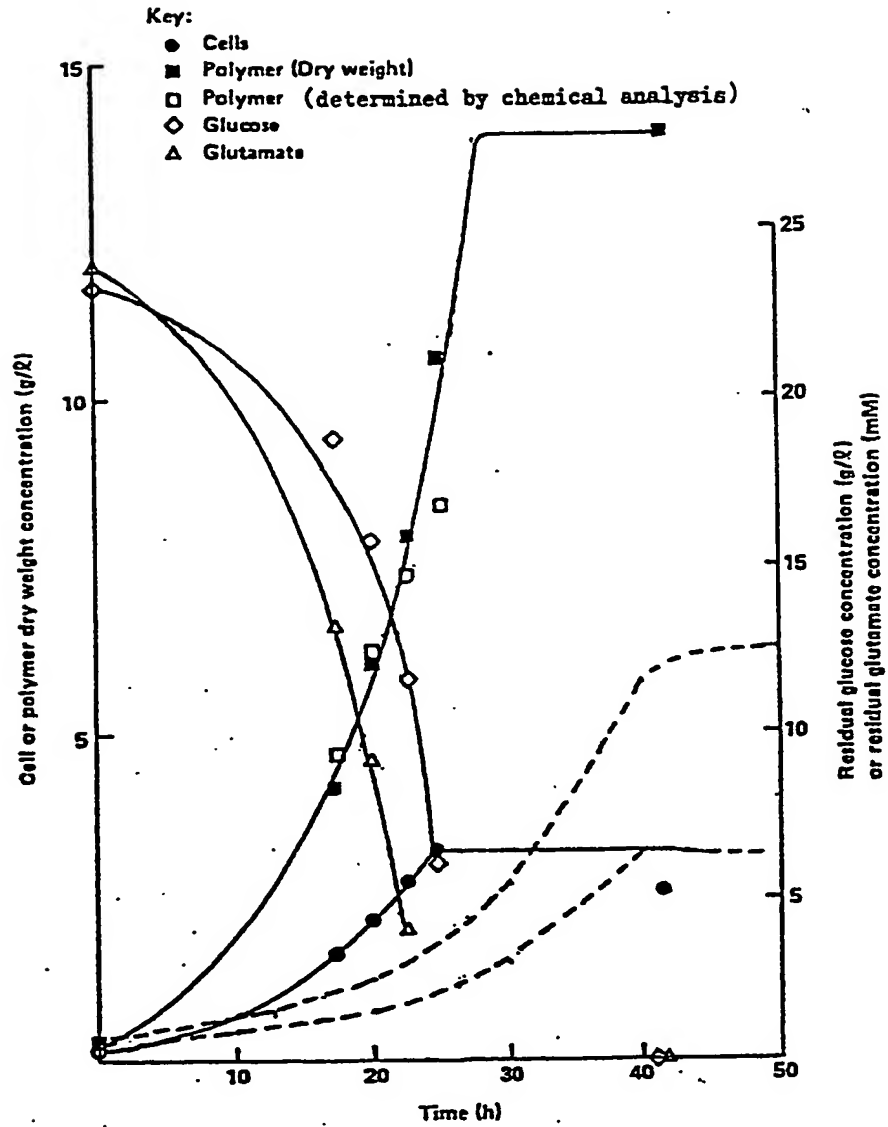


Fig-3. Growth and Polymer Production by *X.campestris* NCIB 11854 (solid Lines) and *X.campestris* NRRL B-1459 (dashed Lines: top, polymer; bottom, cells) in defined salts medium (3) Glutamate as nitrogen source.